

THE PETROLOGY OF THE MARSHALL FORMATION OF MICHIGAN

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ABSTRACT

Study of the petrology of the Mississippian Marshall formation of Michigan indicates that the materials of the formation were chiefly derived from the Laurentian and Huronian terranes or from sedimentary rocks originally derived from these terranes and that the distribution areas were closer to the sites of deposition of the western parts of the state than to the eastern.

Attention has been focused on the Mississippian Marshall formation throughout the history of the state. In the early days it was important as a source of brine, building stone and grindstones, but today the chief interest lies in its use as a key horizon to which test wells are drilled to obtain information relating to structure. It is the most widespread of the near-surface deposits and covers almost the entire Lower Peninsula with the exception of two tiers of counties in the northern part of the state, and about two tiers in the southern part (fig. 1). Outcrops are infrequent due to the deep covering of glacial drift.

LITHOLOGY

The formation is composed of the lower Marshall, and the upper Marshall or Napoleon. The lower Marshall consists of sands and shales with occasional limy layers and, in eastern Michigan a conglomerate containing small pebbles of peanut size often marks the change from the underlying Coldwater shales. There are many layers of red shaly sandstone which usually have a high lime content. In the

center of the Michigan basin this "red rock" horizon seems to be fairly consistent in denoting the change from lower to upper Marshall. In the eastern part of the state, the position of the red layers seems erratic, but they may mark the change from lower Marshall to Napoleon. In some instances this change is indicated by a concentration of muscovite, or a conglomerate consisting of peanut size pebbles, and the "red rock" is then found near the bottom of the lower Marshall.

On the northwestern side of the state, in localities where deep drilling has yielded the information, the two members of the Marshall are practically indistinguishable and the red color and shaly characteristics prevail throughout the formation.

In southwestern Michigan the Marshall formation is thin and the red color is rare.

The lower Marshall has a high iron content and contains much muscovite. The cement is usually lime.

The upper Marshall is a medium-to coarse-grained porous sandstone which in the exposures shows cross-bedding, and a conglomerate is usually found

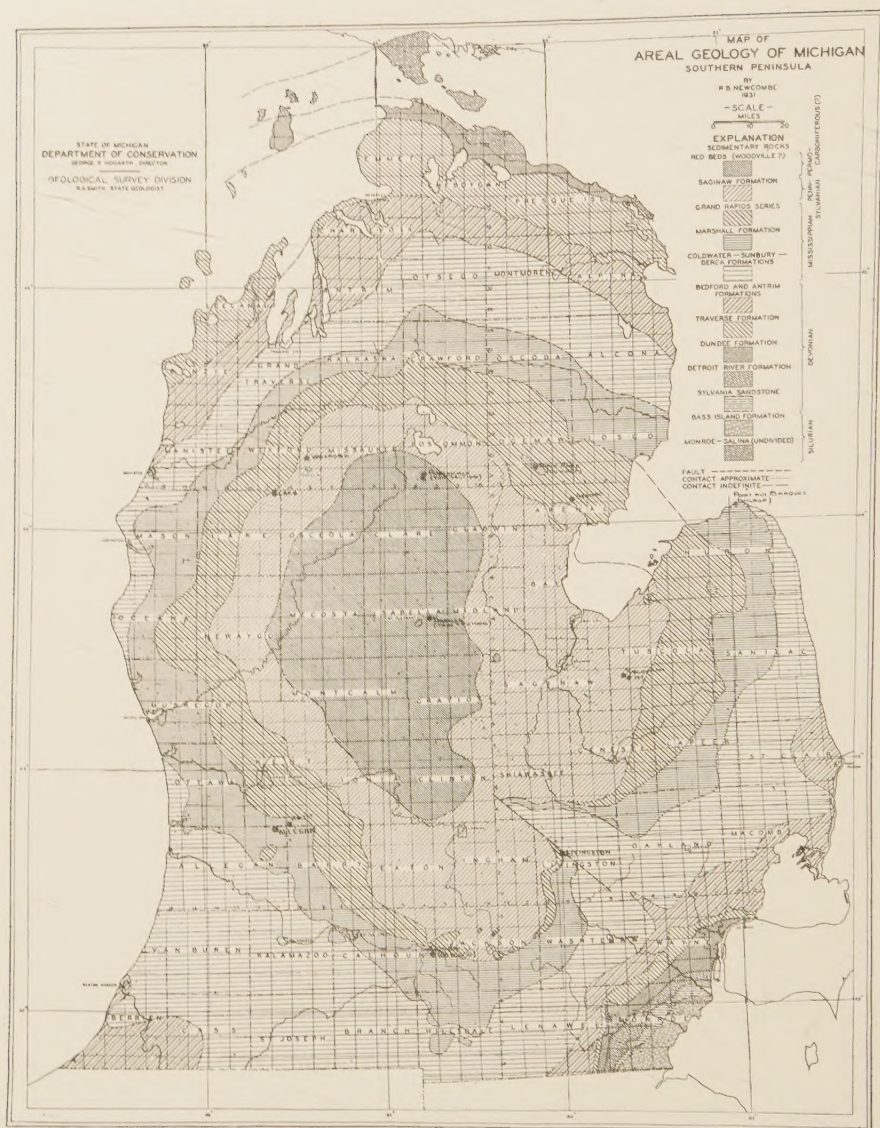


FIG. 1. Geologic map of Michigan showing location of outcrops and wells from which samples were used.

at its base. The color is buff to greenish and is spotted with white or brown resulting from alteration of some constituents. The cementing material is siliceous.

The change from the upper Marshall to the overlying Michigan formation is often indicated by a thin green shale. Near the bottom of the Michigan formation a sandstone of irregular

geographical distribution has been recently discovered. Its lithologic similarity to the Napoleon sandstone led to the conclusion that the Michigan sandstone was derived from the erosion of islands of upper Marshall that projected above the Michigan sea (Newcombe, 1931, p. 84).

The structures of the Marshall sandstone coincide in a broad way with those of the other Paleozoic sediments of the region. The Michigan synclinal basin was early subjected to warping which formed synclines and anticlines within the major syncline. All the Paleozoic deposits, so far as known, follow the irregularities of these original control lines. This condition makes it possible to use the younger formations as a guide to the structures existing in the older beds.

Many small variations found at the top of the upper Marshall are topographic rather than structural, resulting from a period of erosion at the close of Marshall time. Thomas (1930, p. 498) notes a pronounced unconformity between the upper Marshall and the underlying beds on the western side of the state. The Marshall on the eastern side of the state, he says, is conformable to the lower formations, and it is in this region that the Marshall is particularly important as a key horizon. On the western side the usual thickness of the formation is approximately 200 feet, whereas in Huron County 450 to 400 feet are common.

PETROGRAPHY OF THE SEDIMENTS OF THE MARSHALL FORMATION

Both the Pure Oil Company and the State Geological Survey kindly pro-

vided samples from various locations for a petrographic study of the Marshall formation. The samples were given with the understanding that the exact locations be confidential and thus it was not possible to work out a detailed correlation of particular horizons. An attempt was made to obtain a general knowledge of the depositional environment of Marshall sediments, and, based upon a study of the heavy minerals, of the source from which the material of the sandstone was derived.

The samples from Arenac, Tuscola, Livingston, Kent and Allegan Counties (see fig. 1) were taken from core test wells drilled with a light hollow-rod drilling machine. Samples from wildcat wells in Wexford and Lake Counties were also examined. In addition to well cuttings, outcrops from the bed of Rifle River, section 9, Mills Township, Ogemaw County, and from Point aux Barques, Port Austin Township, Huron County were studied. Two thin sections were obtained from the Grayling Development Company's diamond drill cores in Roscommon County, one from a diamond drill core of an Isabella County well, and another from an outcrop in Sanilac County.

Six outcrop samples, three diamond drill cores, and 269 well cuttings were examined during this study. The petrographic determinations were compiled from four thin sections and 279 slides of detrital material.

LABORATORY PROCEDURE

Each bag of the well cuttings is presumably an average sample of 5 feet of the rock section. Fifty grams of each sample were weighed and allowed

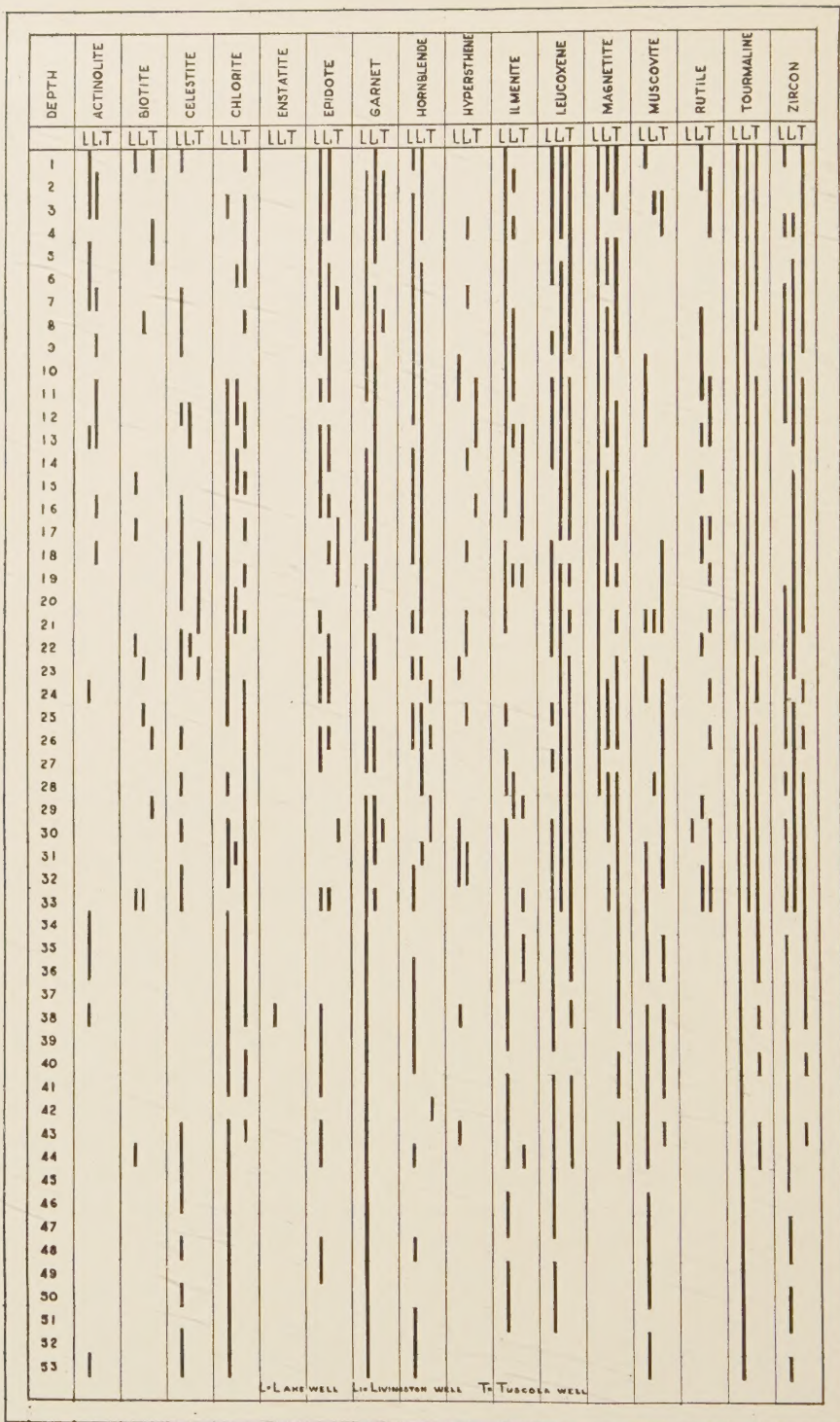


FIG. 2. Graph showing comparative mineral distribution for the Tuscola (T), Livingston (LI) and Lake (L) County wells.
 Figures on the vertical scale represent five foot samples in descending order from number 1—the top of the Marshall.

to stand in a 30 per cent HCl acid bath for 12 to 24 hours, depending on the amount of ferruginous matter present, then washed and dried, and the total loss calculated. Particles less than 0.05 mm. in diameter were lost during the washing process.

For use in the heavy liquid separation, the insoluble residue was screened and the fraction below 0.25 mm. in diameter saved. The size of the sample used for this separation depended on the amount of material available, but wherever possible 15 to 20 grams were taken. Bromoform, which averaged 2.82 in specific gravity, was used as the heavy liquid. Separations were made according to Milner's method (1929, pp. 43-54) and alcohol was used for the washing medium. In general, the residues were so completely flooded with pyrite that other constituents were obscured and to remove the pyrite the grains were submitted to a 30 per cent HNO₃ acid bath for about 8 to 10 hours, and in most instances re-separations were made to eliminate quartz that had been carried down in association with pyrite.

A DESCRIPTION OF THE MARSHALL MINERAL SUITE

The mineral suite of the Marshall formation is neither abundant nor very diversified. Of the light minerals quartz is the most plentiful, forming the bulk of a sample. Minor quantities of feldspar along with its kaolin and sericitic alteration products are also present. Pyrite, magnetite, ilmenite, and leucoxene are the most abundant accessory minerals. After the removal of the opaque species tourmaline re-

mains as the most persistent and common mineral of the eastern region with zircon almost equally frequent and geographically as widespread. Garnet exceeds tourmaline in the western suite of minerals. Actinolite, biotite, chlorite, epidote, hornblende, hypersthene, muscovite, and rutile represent the minor constituents among the high specific gravity residues. Celestite and dolomite are occasionally present.

The western residues are more varied and abundant than the eastern and contain garnet, which because of its stability indicates that the differences between the two suites are inherent, and not the result of varying stages of alteration. Pink zircon, hornblende, epidote, actinolite, and some biotite are also characteristic.

The eastern assemblage is typical of a reworked sediment, and contains only such resistant minerals as tourmaline and zircon, and the alteration products of less stable species. The scarcity of garnet and the absence of pink zircon are conspicuous.

COMPARISON OF THE EASTERN AND WESTERN ASSEMBLAGES

Lake and Tuscola Wells.—The Lake and Tuscola wells were chosen for the comparison because they are representative of the general variety of minerals found in their respective localities, and they constitute the most complete sections available for examination from either side of the state.

The light minerals of the wells are similar. Both contain small amounts of microcline, orthoclase, altered plagioclase, and sometimes muscovite and chlorite. The greatest percentage is

made up of angular to subangular quartz grains, most of which contain rutile arranged in fine parallel lines. The heavy residues are flooded with pyrite. Magnetite is present in only slightly smaller quantities.

The Lake County samples show the most striking difference from those of

never red. Two is the largest number of garnets ever found in a Tuscola slide, whereas 10 to 15 may occur in one from Lake County.

Unstable minerals such as hornblende and actinolite appear frequently in the Lake County samples without much sign of incipient alteration. Ac-

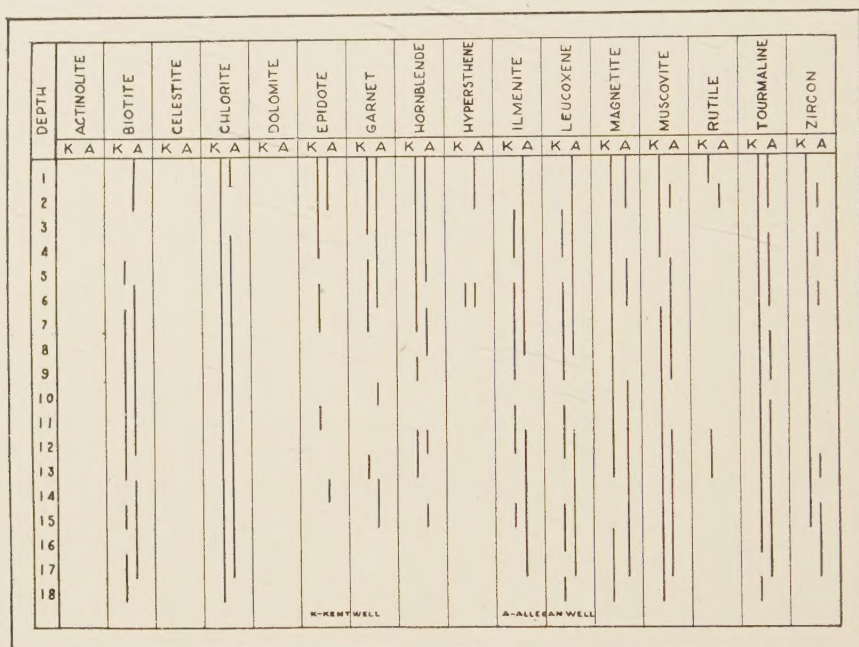


FIG. 3. Graph showing comparative mineral distribution for the Kent (K) and Allegan (A) County wells.

Figures on the vertical scale represent five foot samples in descending order from number 1—the top of the Marshall.

Tuscola County in the frequency and persistence with which garnet appears in the Lake County residues. Pink, orange-red, and colorless garnets occur in that general order of frequency for the entire section, but any one of these three colors may dominate in a single slide. In the eastern well garnets are present in but four of the 44 slides, and they are either pink or colorless,

tinolite does not occur in the Tuscola residues at all, and hornblende is rare. That the latter has been replaced in most instances by chlorite is known from observing grains in which the process is incomplete. Epidote and hypersthene are more persistent and abundant in the western well than in the eastern region.

Differences in the ilmenite-leucoxene

ratio are not so apparent on the graph as they are on the slides. However, in the Tuscola well leucoxene is persistent whereas ilmenite does not appear until a depth of 55 feet below the top of the Marshall (see fig. 2). Leucoxene is recorded as "on ilmenite," or simply as "leucoxene," showing it to be the more important of the two constituents. In the Lake County sands, on the other hand, ilmenite is very persistent and is described as "ilmenite—with little leucoxene alteration," or "Ilmenite flooding—little leucoxene," indicating that ilmenite is the dominant form. Furthermore, many ilmenite grains of the western residues have fresh unaltered surfaces, an occurrence which has never been observed in the Tuscola samples.

Thus we see that the Lake and Tuscola residues have distinct heavy mineral assemblages, which may be summarized as follows:

Lake County: The abundance of fresh ilmenite, hornblende, actinolite, and epidote, together with the presence of garnet and pink zircon characterize this suite of minerals.

Tuscola County: Abundant products of alteration such as leucoxene and chlorite, rarity of garnet, and total absence of pink zircon and actinolite differentiate this assemblage from the Lake County suite.

Discussion of All Eastern and Western Residues.—No actinolite is present in the samples from the Kent and Allegan wells (fig. 3). Fresh hornblende is common and quite persistent. Epidote is plentiful when it occurs, but is not as well distributed throughout the section as in the Lake County samples.

Garnets are common and the orange-red color is a characteristic feature. Ilmenite is present with fresh unaltered surfaces whereas leucoxene is a minor constituent. Pink zircon is frequent.

Garnet and epidote are rare in both of the Tuscola wells, and in the Arenac samples. No actinolite is present; hornblende is infrequent and shows signs of alteration when it does appear. Leucoxene is almost universally present, but ilmenite was not often observed. Neither was pink zircon found.

It is apparent that the eastern residues characteristically show the effects of alteration in the presence of large amounts of leucoxene and minor quantities of ilmenite; by the absence of most of the ferro-magnesian minerals or the advanced stage of weathering in which the hornblende occurs. Orange-red garnets are absent, and the pink to colorless varieties are scarce. Only colorless zircon appears.

The western assemblage is characterized by the presence and abundance of garnet—particularly the orange-red species; by pink zircon; and by the dominance of fresh ilmenite and ferro-magnesian minerals.

RELATION OF LIVINGSTON RESIDUES TO THE EASTERN AND WESTERN ASSEMBLAGES

The Livingston well is located (fig. 1) on the southwestern or downthrown side of the Howell-Owosso fault and the entire thickness of the Marshall was available for study. The suite of minerals is large and the variety of species is as great as in the Lake County well (fig. 2).

The vertical continuity and the

abundance of garnet, particularly the orange-red variety, is very striking. Hornblende, epidote, and actinolite are also common and persistent. The presence of garnet, and the freshness of the unstable minerals in the Livingston suite indicates a close relationship to the western assemblages. From the standpoint of the ilmenite-leucoxene ratio the Livingston residues have a greater resemblance to the eastern samples. Ilmenite is somewhat more abundant than in the eastern suite, but it is not as common as in the typical western residues.

The presence of fresh amphiboles, which are themselves unstable, argues against prolonged transportation as the reason for such an increased percentage of leucoxene. According to Milner (1929, p. 445) the causes of transformation from one titanium mineral to another are not well known but he suggests that the ilmenite form is more common in connection with an iron mineral environment. Therefore in the Lake County samples where iron minerals dominate, ilmenite is also abundant, whereas in the Livingston area where iron minerals are much less important, leucoxene is more frequent.

Another possible explanation is that the position of the Livingston well close to the fault line made these samples subject to alteration by meteoric waters. On the basis of the conditions in the Kent and Allegan wells and on their similarity to the Livingston conditions, however, the first explanation is probably preferable.

Actinolite in the Livingston suite, since it does not appear in the Kent and Allegan residues, presents another

problem. The latter wells, however, show only the lower 92 feet of the Marshall section and in the Livingston samples actinolite is not found in the lower 73 feet of Marshall sandstone. It is probable that the lower portion of the Marshall underwent a more rigorous decomposition than was suffered by the younger sediments leading to destruction of the actinolite of the Kent and Allegan wells, and the lower part of the Livingston section.

It is obvious that a close affinity, evident on the basis of the orange-red garnet alone, exists between the Livingston and western assemblages. It seems strange that this should be true when the Livingston and Lake wells are separated by 140 miles, as compared to a distance of 70 miles between the Tuscola and Livingston locations.

On the northeastern side of the fault which has already been mentioned, an anticline separates the Tuscola and Livingston localities. In spite of extensive testing no Marshall outliers have been discovered on the upthrown side of the fault, and it is possible that the Marshall sea never covered this region. If such a barrier did exist, it would prevent a mingling of the eastern and southern drainage systems, and the two sides of the fault would have unrelated suites of minerals as long as differences existed in the source rock from which each was derived.

THE SOURCE OF THE MATERIAL AND THE ENVIRONMENT OF DEPOSITION OF THE MARSHALL FORMATION

Problems of the Distributive Province.—In order to determine the sources of the materials and the con-

ditions under which Marshall sediments were deposited, the distributive province, or provinces must be known. Two major considerations, namely, the rocks contributing to the basin, and the features which controlled the direction of drainage must be understood. For this purpose a short résumé of the geology of the area adjoining Michigan is attempted.

Structures Delimiting the Province.

—The Cincinnati arch: To the south of Michigan the Cincinnati arch is the major structural feature. The arch developed in late Ordovician or early Silurian time, and influenced drainage through much of the subsequent Paleozoic.

The Indiana extension of the structure has been described by Malott (1932, p. 128) to have its axis stretching from the crest in Jessamine County, Kentucky, northwestwardly toward Richmond and Logansport, Indiana, descending in this direction until in the vicinity of Logansport the strata rise again along the axis which here trends toward the region of Chicago. Eventually the arch becomes a part of the Wisconsin uplift.

On the northwestern side of the Indiana arch the dips are low and the rocks incline into the Michigan basin.

Wisconsin Uplift: The Paleozoic sediments dip away from the crest toward the west and east according to Martin (1911, p. 87). This uplift passes northward through the central part of Wisconsin.

Pre-Cambrian Highlands: The northern uplands of pre-Cambrian rocks constitute almost the entire Lake Superior district and extend through

Canada, past the northern end of Lake Huron toward the eastern coast of North America. A neck of pre-Cambrian rock extends southeast and, crossing the St. Lawrence at the Thousand Islands, divides the Paleozoic rocks into two distinct areas.

Ontario Peninsula: Passing southward from the Lake Superior area into the Ontario Peninsula of Canada, Paleozoic sediments show the presence of rather small dips toward the Michigan synclinal basin, and away from the central pre-Cambrian axis. This southwesterly dip continues to the region lying between Lake Erie and the south end of Lake Huron. From this section a gradual rise of the strata toward the southwest occurs (Malcolm, 1915, p. 45).

Summary of Structural Control.—

It is evident from the foregoing that Michigan is surrounded by a set of structures which isolated the basin throughout much of Paleozoic time. In the southern region the Cincinnati anticline has acted as a barrier since late Ordovician: toward the west the Wisconsin arch has resulted in dips toward the Michigan basin: in the north the pre-Cambrian uplands of the Lake Superior region have enclosed the basin in that direction, on the east, dips have been away from the pre-Cambrian mass, which in Ontario resulted in inclination toward the Michigan basin.

Thus drainage has been toward the Michigan synclinal basin throughout much of Paleozoic time.

Rocks of the Distributive Province.

—Ohio and Indiana: The rocks of these two states which are available as source material for Michigan de-

posits lie on the western flank of the Ohio anticline, and on the eastern flank of the Indiana uplift. Available material is of sedimentary origin and made up principally of limestone.

Wisconsin: The deposits of southern and central Wisconsin are Paleozoic. They form a great semicircle around the pre-Cambrian peneplain of the central and northern parts of the state. The Cambrian of Wisconsin is a sandstone, and the Ordovician and Silurian strata are limestones.

Lake Superior Region: The rocks are crystallines of both igneous and sedimentary origin, and Keweenaw clastics, volcanics and plutonics.

Zircons, garnets, amphiboles, epidote, tourmaline, titanium minerals, and occasionally hypersthene and enstatite have been found in the Lake Superior crystalline rocks. They are usually recorded as occurring in gneisses, schists, and metamorphosed graywacke.

Pre-Cambrian of Canada: The crystalline rocks in the region adjoining eastern Michigan are granite-gneisses, gneisses, granite, and some schists. The younger Huronian rocks consist of clastics and eruptives.

The minerals recorded from this district of Canada are hornblende, epidote, biotite, chlorite, zircon, garnet, ilmenite accompanied by leucoxene, rutile, and tourmaline. Of these species zircon, epidote, chlorite and hornblende are most frequent. Garnets are rare, occurring only in garnetiferous schists.

Ontario Peninsula: Malcolm (1915, p. 5, 9) describes the rocks of Ontario, Canada. Limestones, dolomites, and shales of the Ordovician, Silurian, and

Devonian periods rest upon formations of pre-Cambrian age. A few feet of sandstone and arkose, possibly Potsdam, occurs at the base of the section.

Summary of Rock Types.—From the southerly direction only limestones and shales are available source material for Marshall sediments. Possibilities range from middle and upper Ordovician through the Devonian, with emphasis on the Devonian, since that formation seems to have been the most widespread.

From the west and northwest, in addition to the Ordovician and Silurian limestones, Cambrian and Ordovician sandstones are possible sources. In the northwest, north, and northeast crystalline rocks are also exposed and were undoubtedly the original rocks from which came most of the Marshall sandstone. To the east were Ordovician, Silurian, and Devonian formations, and crystalline rocks as source materials.

Source of Marshall Sediments.—Mechanical sediments derived from the south are very rare, at least within the triangular area adjacent to Michigan, and bounded by the Cincinnati arch. The thin layers of the Sylvania and Pendleton sandstones of Ohio and Indiana respectively, are the only sources of sandstone. These formations could not, of course, have contributed any appreciable amount of sand toward the thick Marshall section.

Drainage off the Cincinnati anticline into the Michigan basin must have brought in large amounts of chemical sediments, and possibly some silt. Any other material would be out of the question due to a lack of source material in the distributive province.

From the standpoint of available material the southern sources prove decidedly inadequate.

Condit (1912, pp. 153-163) has studied Ohio sands petrographically and from his microscopic work there is further evidence that Ohio sandstones are not closely related to the Marshall formation.

The sandstones of Ohio from the Permo-Carboniferous and older formations contain minerals such as quartz, muscovite, kaolin, microcline, zircon, limonite, orthoclase, plagioclase, sericite, hematite, apatite, chlorite, pyroxene (altered), pyrite and marcasite.

Condit (1912, p. 159) says that the scarcity of garnet is characteristic of all sandstones of, and older than, Carboniferous age which had been studied at that time.

On the western side of Michigan the Wisconsin and Lake Superior regions provide an adequate primary source for mechanical sediments in the pre-Cambrian crystalline rocks. The immediate source may have been the Cambrian sandstones and Ordovician limestones.

Two of the lower members of the Cambrian sandstone (the Jordan and Madison) of Wisconsin have been studied petrographically by Ockerman (1930, pp. 346-354). He finds (p. 350) that 90 per cent of the residues of the eastern Wisconsin sandstone consists of garnet, as compared to 75 to 80 per cent for the residue from the western sandstone. Zircon is next most abundant, with tourmaline third. This high percentage for garnet could hardly persist during a reworking of the sandstone, but in the western Marshall

sandstone garnet still predominates over tourmaline and zircon.

In addition to the abundance of garnet, there is another possible indication of the important influence of metamorphic rocks in the presence of pink to purplish zircon in the western Marshall residues.

On the other hand, rarity of garnet and the absence of purple zircons in the eastern Marshall sediments, suggest that the most important source rock was igneous rather than metamorphic.

Mackie (1923, p. 201) observed purple zircon in specimens of gneiss from Canada, but found only colorless zircon in the granite-gneiss which resembles granite in every particular except that it is more or less foliated. Since the Laurentian granite-gneiss is the most widespread of the crystalline rocks of the Canadian region under consideration it probably was the chief source of the eastern Marshall sediments, whereas true gneisses and schists contributed the major portion of the western Marshall sediments. However, until samples of these crystalline rocks have been examined by crushing and study of the heavy residues no more definite conclusion can be reached.

The presence of hornblende, actinolite, and epidote in the the western residues indicates that their source was comparatively near at hand, because these ferromagnesian minerals are too unstable to endure prolonged transportation.

Scarcity of ferromagnesian minerals, the advanced stage of alteration of such of these minerals as do occur,

and the presence of leucoxene almost to the exclusion of ilmenite point to a complicated history of weathering, and prolonged transportation before the deposition of the sediments in the Marshall sea.

Either the north end of Lake Huron or the region of the Frontenac axis is far enough away from Michigan to account for a long period of transportation. Such a distant source makes it difficult to determine just when the major portion of the weathering took place, but although much of the decomposition must have been accomplished during the transportation, undoubtedly some preceded it.

Topographic irregularities at the top of the upper Marshall indicate that the younger part of the formation was exposed to agents of weathering and erosion after deposition, and some alteration to gibbsite has taken place.

Summary of Rock Sources of Marshall Sediments.—The Wisconsin and Upper Peninsula rocks have furnished vast quantities of sediment to the western and southern deposits of Marshall sandstone. The rocks of Canada, primarily the Laurentian granitic-gneiss and the débris therefrom, furnished the major portion of the material for the eastern deposits of Marshall sandstone.

The northern extension of Marshall is as yet almost untouched by the drilling program, and it can only be surmised that the source material resembles that of the Lake County well.

The Paleozoic rocks have not been able to contribute mechanical sediments in large enough quantities to be appreciable in the deposition of Marshall

sediments, but these areas probably provided cementing material.

Climate.—Were the Marshall formation derived directly from crystalline rocks, the degree of alteration of the feldspars would be a means of postulating climatic conditions for the period. However, the source of the Marshall is somewhat indirect and much of the kaolinization must have occurred during previous erosion cycles.

Due to decomposition, feldspars are not easily identified in Marshall residues, and the small amount still fresh may show direct origin in the pre-Cambrian rocks.

Since hornblende is still fresh in the western wells it may suggest that the Marshall climate was unfavorable to decomposition. However, since amphiboles are so abundant in the source rock, it is more probable that hornblende indicates a direct source from the hornblendic schists of the Laurentian and Huronian rocks.

The alteration which caused the formation of gibbsite was undoubtedly accomplished in a warm climate. Evidence of high temperature and aridity toward the close of the Marshall are found in the saline, gypsum, and lime deposits which succeed the Marshall formation.

Transportation and Deposition.—The uniform extent and thickness of the Marshall formation indicates that a well developed drainage system must have been responsible for its accumulation.

Probably the residual soil of the distributive provinces was removed and deposited during Coldwater and lower Marshall times. As rock disintegration

became increasingly important during Marshall time due to gradual uplift, bed rock itself was eroded. Thus the upper Marshall includes both unweathered *débris* and some products of alteration. The western deposits of the Marshall sandstone contain both the red ferric hydroxide products of decomposition, and fresh ferromagnesian minerals.

The eastern deposits of Marshall are colored by iron minerals only in the older part of the formation, probably because iron sources were not so abundant to the east.

Heavy residues show no more relationship between the eastern and western sandstones of red color, than between those of buff and red colors, showing that the rock colors in themselves are an inadequate basis for supposing that the lower Marshall of the two sides of the state had the same origin.

Grain size determinations indicate fairly uniform textures within the 0.10 mm. and 0.50 mm. limits. The quartz grains are angular to subangular and suggest transportation by water.

After, and possibly during the deposition of the Marshall formation, precipitation of secondary quartz took place, and along with calcite filled the interstices between sand grains. Pyrite, some magnetite, and possibly marcasite were abundantly precipitated. The pyrite seems to have had a special affinity for the solution pits of quartz

grains. In some of the sediments celestite was also deposited in small amounts.

CONCLUSIONS

From a study of the heavy residues of the Marshall sandstone it has been determined that:

1.—The formation was derived chiefly from the Laurentian and Huronian rocks and the *débris* therefrom (such as the Cambrian and Ordovician sandstones).

2.—The source of the western sediments was nearer than the source of the eastern sediments. This condition resulted in differences in the mineral assemblages of the two regions.

3.—The residues from southern Michigan sediments are more closely allied to the western than to the eastern residues, undoubtedly because of structural conditions. Livingston was hardly affected by possible southern sources due to the type of rock in the southern distributive province.

4.—The sandstone of Marshall time was a marine deposit, owing its origin chiefly to the material contributed by a well developed drainage system.

5.—The depositional basin was areally extensive, and gradually became more shallow throughout the period. Much of the land appeared above water during the end phase of upper Marshall deposition, and erosion caused topographic irregularities between the Marshall, and the succeeding Michigan formation deposits.

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